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ABSTRACT: A major portion of the cost of using Granular Activated Carbon (GAC) as a water treatment unit process is associated with spent carbon replacement or reactivation. Regional reactivation or sharing a reactivation furnace among several users, has been proposed as a means of minimizing this cost. To test this concept, a field scale regional reactivation project was conducted by the Manchester, New Hampshire Water Works in conjunction with three other water utilities. Each of the three participating utilities provided 40,000 pounds of carbon to be transported to Manchester for fluidized bed reactivation. Data was gathered on reactivation operations and costs, and transportation costs and carbon losses. Results of the study demonstrated that regional reactivation can be cost effective as compared to virgin carbon replacement and in certain instances more cost effective then on-site reactivation.

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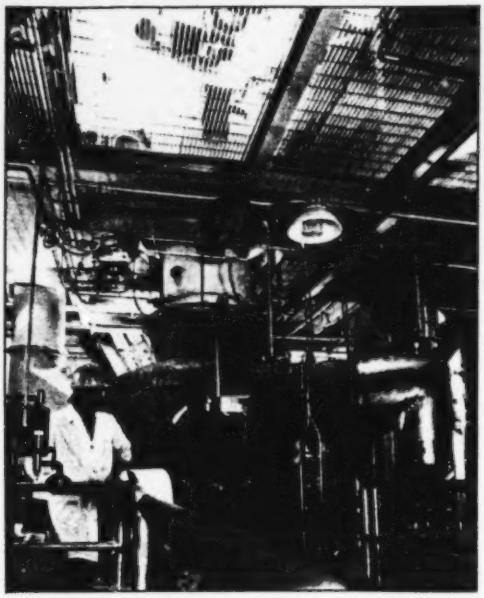

The excess capacity of this fluid bed carbon regenerator at Manchester, N.H., was the impetus for testing the feasibility of regional reactivation.

Regional Reactivation of Granular Activated Carbon

Jeffrey Q. Adams, Robert M. Clark, Benjamin W. Lykins Jr., and David Kittredge

A major portion of the cost of using granular activated carbon as a water treatment unit process is associated with the replacement or reactivation of spent carbon. Regional reactivation—the sharing of a reactivation furnace among several users—has been proposed as a means of minimizing this cost. To test this concept, a field-scale regional reactivation project was conducted by the Manchester (N.H.) Water Works in conjunction with three other water utilities. Each of the three participating utilities provided 40 000 lb (18 160 kg) of carbon to be transported to Manchester for fluidized-bed reactivation. Data were gathered on reactivation operations and costs, transportation costs, and carbon losses. Results of the study demonstrated that regional reactivation can be cost effective compared with carbon replacement and, in certain instances, compared with on-site reactivation.

The use of granular activated carbon (GAC) as a broad-spectrum adsorbent for treating drinking water has been shown to be effective in removing or reducing concentrations of specific organics and total organic carbon (TOC).[1] Because removal of TOC by GAC adsorption ensures that most of the specific organics have been removed, the general parameter of TOC was used at several field locations to determine the performance of GAC. When various GACs were evaluated for organics removal, the coal-based GACs were found to result in the best removals over a long time period. Using steady-state TOC as an evaluation criterion, it was determined that the service life of GAC would generally be three months before replacement or reactivation. Granular activated carbon was effectively reactivated in the field-scale studies, with the performance of reactivated GAC being comparable with if not better than that of virgin GAC.

Managers of many drinking water utilities whose raw water supplies are vulnerable to contamination by synthetic organics have shown an interest in the use of GAC. One large drinking water utility, the Cincinnati (Ohio) Water Works (CWW), is in the process of modifying its treatment system to include GAC.[2] The utility's plan includes the use of postfiltration GAC adsorption contactors and on-site reactivation.

A number of utilities, many of them small water systems, have recently found volatile organic compounds in their groundwater sources. Concern over groundwater contamination has intensified interest in the use of GAC, but high unit costs are generally associated with discarding spent carbon or installing on-site carbon reactivation systems. Off-site or regional reactivation offers the possibility of minimizing these costs.

Earlier US Environmental Protection Agency (USEPA) investigations evaluated the cost of field-scale GAC treatment research facilities at CWW and the Manchester (N.H.) Water Works (MWW).[2,3] Another report presented cost estimates for various GAC treatment scenarios in order to examine the effect of economies of scale.[1] The primary focus of these efforts was to examine the costs of steel or concrete GAC contactors and on-site reactivation using fluid-bed, infrared, and multihearth technologies. Cost estimates for complete on-site GAC treatment systems (adsorption and reactivation) ranged from about $0.45/1000 gal (3785 L) for cost-effective small treatment plants to about $0.20/1000 gal (3785 L) for large treatment plants. The reactivation process was found to contribute approximately 50 to 75 percent to the total cost of the GAC treatment system.

Because of the significant economies of scale inherent in larger systems, the concept of regional GAC reactivation seemed feasible. Under a cooperative agreement with MWW, institutional and operational problems associated with regionalization were evaluated and the economies of regional reactivation were

TABLE 1
Capital costs for carbon reactivation at Manchester, N.H.

Item	Cost—$
Carbon reactivation building	226 900
Fluid-bed system (500-lb/h [226.8-kg/h] capacity)	528 600*
Carbon transport system (four filters)	120 000*
Analytical equipment	38 400
Analytical supplies (glassware, gases, reagents)	3 700
Contractual services (architectual and engineering fees for building design)	25 800
Personnel costs (MWW)	22 300†
Virgin GAC for test filter	49 500
Material testing services	7 100
Total	1 022 300

*Includes installation and equipment costs
†Does not include overhead costs

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examined. This article discusses the results of the study.

The Manchester regional reactivation system

The fluid-bed GAC reactivator built at MWW to evaluate the performance and cost of a full-scale, on-site GAC reactivation system has a throughput capacity of approximately 500 lb (226 kg)/h (3.6×10^6 lb [1.6×10^6 kg] GAC/year), assuming a reasonable operating factor of about 75 percent. Assuming continuous operation, it takes less than four months to reactivate the entire 1.0×10^6 lb (453 000 kg) of GAC used at the MWW treatment plant in any given year.

Given this excess capacity and an interest in the possibility of using the Manchester furnace as a regional reactivator, MWW developed a project that incorporated the concept of regional reactivation. The first step of the project involved conducting a survey of water utilities in New England that use GAC and making an estimate of their reactivation requirements. All of the 19 water treatment plants contacted expressed an interest in the concept. After careful evaluation, and for the purposes of this study, a limited regional reactivation program was executed that involved three water utilities: Connecticut Water Company's Kelseytown treatment plant; the Danvers, Mass., water treatment plant; and the Lowell, Mass., water treatment plant. Each of the participating utilities agreed to provide approximately 40 000 lb (18 160 kg) of carbon to be transported to Manchester and reactivated. Before any reactivation for the two utilities in Massachusetts could be started, the approval of the State Department of Environmental Quality Engineering had to be obtained. The project was begun in the fall of 1981.

The primary cost objectives of the GAC research project conducted at MWW were:

- to document the costs associated with operating a full-scale, on-site, 12 000-lb (5443-kg)/d, fluid-bed GAC reactivation system, and
- to document the costs associated with reactivating GAC on a limited basis for other New England water utilities.

Costs of on-site reactivation system

During the original two-year operating phase of the research project, about 3.6×10^6 lb (1.6×10^6 kg) of MWW's carbon was reactivated on an intermittent basis. Rather than develop costs based on two years of intermittent operation, a more representative analysis was made with data from a period of steady-state operation—June 1980 through March 1981—which followed improvements made to the original reactivation system. The uptime operating factor of the reactivator for this period was about 70 percent, and during this period MWW reactivated 1 857 176 lb (842 415 kg) of carbon.

The capital costs for the MWW reactivation system are given in Table 1. Table 2 shows the capital expenses allocated to equipment- and building-related components and the depreciation cost used in calculating the on-site and regional reactivation costs. These costs represent actual production.

The capital costs associated with the analytical equipment and supplies were not included in the depreciation cost because they are primarily related to research and not representative of normal operations. The capital cost for the carbon transport system was not included in the depreciation cost because the system was not used during the operational period on which the analysis is based. The unit depreciation cost was based on an effective use of 75 percent over 365 days for 24 hours per day.

The movement of carbon proved to be a particularly challenging problem. Prior to the period of efficient reactivation, the semiautomatic carbon transport device had been abandoned because of incompatibility with existing filter equipment, faulty new equipment, excessive maintenance, and inability to remove all of the filter media. The projected cost to improve one of the transport mechanisms was in excess of $22 000, which was not covered in the research budget. Nevertheless, the staff at MWW felt that the concept was sound and that ultimately, with design modifications, it could be an efficient method.

The most practical method for on-site carbon transport was found to be a manual hose and eductor system. An operator could transport approximately 2000 lb (900 kg) of GAC in about 20 to 25 min and could remove 100 percent of the GAC from each cell section of the filter.

TABLE 2
Cost of depreciation of buildings and equipment at Manchester Water Works

Item	Equipment	Building	Total
Construction cost (Table 1, items 1 and 2)—$	528 600	226 900	755 550
Other capital cost (Table 1, items 6-9)—$	73 255	31 445	104 700
Total capital cost—$	601 855	258 345	860 200
Annual depreciation—$	40 124*	7 381†	47 505
Unit depreciation cost‡—$/reactivation hour			7.23

*Estimated useful life of 15 years
†Estimated useful life of 35 years
‡Assumes 6570 reactivation hours per year

TABLE 3
*On-site reactivation costs incurred by Manchester Water Works—June 1980-March 1981**

Cost Item	Total Costs $	Resources Utilized	Unit Costs
Makeup carbon	131 349	213 575 lb (96 876 kg)	$0.615/lb ($1.36/kg)
Labor for reactivation	36 029	4922 work hours	$7.32/h
Labor for transportation	5 200	710.4 work hours	$7.32/h
Labor for laboratory	929	122.9 work hours	$7.56/h
Labor for administration	24 515	2074 work hours	$11.82/h
Parts and service calls	49 587	NA†	NA
Fuel oil	41 415	40 015 gal (151 m³)	$1.035/gal ($274.27/m³)
Electrical power	9 286	175 207 kW·h	$0.053/kW·h
Water	13 743	42 813 084 gal (162 064 m³)	$0.321/1000 gal ($0.854/m³)
Laboratory supplies	929	NA	NA
Depreciation	39 587	3570 reactivation hours	$47 505/year for 10 months
Overhead	51 338	NA	77 percent of all MWW labor
Total	403 907		

*Costs based on reactivation of 1 857 176 lb (842 415 kg) of GAC
†NA = not applicable

TABLE 4
Costs of on-site reactivation per pound (kilogram) of GAC at Manchester Water Works—June 1980-March 1981

Cost Item	Unit Cost*	
	$/lb GAC	$/kg GAC
Makeup carbon	0.0707	0.1559
Labor for reactivation	0.0194	0.0428
Labor for on-site transport	0.0028	0.0062
Labor for laboratory	0.0005	0.0011
Labor for administration	0.0132	0.0291
Parts and service calls	0.0267	0.0587
Fuel oil	0.0223	0.0492
Electrical power	0.0050	0.0110
Water	0.0074	0.0163
Lab supplies and outside analyses	0.0005	0.0011
Depreciation	0.0213	0.0470
Overhead	0.0276	0.0608
Total cost	0.2174	0.4792

*Unit costs based on reactivation of 1 857 176 lb (842 415 kg) of GAC

This method of carbon transport was quick, simple, efficient, inexpensive, and virtually maintenance free.

Table 3 presents a detailed breakdown of the total on-site reactivation costs. As explained previously, these costs are based on actual expenses incurred during the selected 10-month period and exclude expenses related to nonrepresentative research aspects of the project. Table 3 displays both unit and total costs and the amounts of resources utilized.

The largest single operating cost time is the makeup carbon associated with GAC losses from reactivation and on-site handling, representing 33 percent of the total reactivation system cost. The average total carbon loss resulting from on-site transport and reactivation was 11.5 percent by volume. This was based on five reactivation cycles (the utilization of carbon for adsorption followed by its reactivation). To characterize losses throughout the system, three measured losses were determined: filter to filter, reactivation only, and transport.

Total overall labor expense, including labor overhead, represents about 29 percent of the total system cost. Capital cost (depreciation) represents only about 10 percent of the total system cost. A summary of the unit cost (cost per pound [kilogram] of GAC) by cost item is presented in Table 4.

The cost-effectiveness of on-site fluid-bed reactivation was clearly demonstrated, because carbon was reactivated at a total unit cost of $0.217/lb ($0.479/kg) versus a cost of purchasing virgin carbon at $0.615/lb ($1.36/kg).

The cost of makeup carbon is based on an average total volume carbon loss of 11.5 percent at a delivered cost to Manchester of $0.615/lb ($1.36/kg). Labor for operation and maintenance of the reactivation and transport systems is based on a staff of 12 operators at an average wage of $7.32 per hour. Each operator spent an average of 9.4 hours of a 42-hour workweek operating and maintaining the GAC reactivator and an average of 1.6 hours transporting GAC between the filter beds and the reactivator. Labor costs for laboratory analysis to monitor the quality of the reactivation process are based on a staff of one laboratory technician at a wage of $7.56 per hour. This technician spent an average of 9.8 hours of a 35-hour workweek on GAC reactivation work. Labor for administration is based on a staff of two engineers, a chemist, a secretary, a purchasing agent, and an accountant. Each person spent an average of 9.8 hours of a 35-hour workweek on work associated with GAC reactivation.

Parts and service calls are based on a total cost of $49 587 for new parts, repair charges, and outside service (excluding MWW staff). Fuel oil costs are based on an average cost of $1.035/gal ($0.273/L) of fuel oil and consumption of 11.2 gal (42.4 L) per hour of reactivation for 2994 Btu/lb (6601 Btu/kg) GAC. Electrical power cost is based on an average cost of $0.0532/kW·h and a consumption of 48.6 kW per hour of operation for process and building energy, or 0.032 kW·h/lb (0.205 kW·h/kg) GAC. Water cost is based on a water production cost of $0.321/1000 gal ($0.848/m³) and a consumption of 11 792 gal (44.64 m³) per hour of operation, or 22.7 gal/lb (0.189 m³/kg) GAC. About 92 percent of the water used was for reactivation and 8 percent for transport.

The total cost of laboratory supplies to perform quality control analysis for the reactivation process was $929. Depreciation is based on the straight-line method (Table 2). Overhead is based on a MWW overhead factor of 77 percent above labor costs, which include holidays, vacations, sick leave, and fringe benefits.

TABLE 5

Comparison of costs of regional reactivation with those of GAC replacement and on-site reactivation—1981

Utility	Cost of Regional Reactivation*		Cost of Replacement With Virgin GAC†		Estimated Reactivation Demand		Estimated Cost of On-Site Reactivation‡	
	$/lb	$/kg	$/lb	$/kg	lb/year	kg/year	$/lb	$/kg
Connecticut Water Company	0.6624	1.4603	1.007	2.2045	96 000	43 000	1.387	3.057
Danvers, Mass.	0.3750	0.8267	0.634	1.3977	90 000	40 000	1.389	3.062
Lowell, Mass.	0.4495	0.9909	1.005	2.2156	250 000	113 000	0.773	1.704

*Includes off-site transport of GAC
†Based on approximately 40 000 lb (18 160 kg) of GAC for each utility
‡Based on cost equations developed from various field-scale GAC studies and other sources of information[1,4]

TABLE 6

Breakdown of the costs of regional reactivation for the three participating utilities Nov. 16-21, 1981

Cost Item	Cost*					
	Connecticut Water Co.		Lowell, Mass.		Danvers, Mass.	
	$/lb	$/kg	$/lb	$/kg	$/lb	$/kg
Makeup carbon	0.2608	0.5750	0.1744	0.3844	0.0836	0.1843
Labor for reactivation	0.0636	0.1402	0.0464	0.1023	0.0395	0.0871
Labor for transportation	0.0212	0.0467	0.0129	0.0284	0.0133	0.0293
Equipment for transportation	0.0537	0.1184	0.0310	0.0683	0.0414	0.0913
Labor for laboratory	0.0028	0.0062	0.0024	0.0053	0.0028	0.0062
Labor for administration	0.0385	0.0849	0.0198	0.0437	0.0178	0.0392
Parts and service calls	0.0418	0.0922	0.0373	0.0822	0.0430	0.0948
Fuel oil	0.0308	0.0679	0.0242	0.0534	0.0308	0.0679
Electrical power	0.0113	0.0249	0.0113	0.0249	0.0136	0.0300
Water	0.0232	0.0511	0.0131	0.0289	0.0151	0.0333
Laboratory supplies	0.0027	0.0060	0.0024	0.0053	0.0027	0.0060
Depreciation	0.0150	0.0331	0.0115	0.0254	0.0149	0.0328
Overhead	0.0970	0.2138	0.0628	0.1384	0.0565	0.1246
Total cost	0.6624	1.4604	0.4495	0.9909	0.3750	0.8268

*Based on reactivation of approximately 40 000 lb (18 160 kg) of GAC for each utility

Costs of regional reactivation

After the performance and cost of an on-site, fluid-bed GAC reactivation system had been evaluated, the use of the facility for regional reactivation was investigated. Initially, the cost and performance of off-site reactivation for other utilities was evaluated.

An open-top-trailer dump truck with a volumetric capacity of 12 000 cu ft (340 m³), which corresponded approximately with the capacity of the spent and reactivated storage tanks at MWW, was selected for on-site GAC transport. This single transport truck was modified to incorporate a watertight tailgate so that there would be no spillage. The amount of GAC that could be hauled by road was governed by state laws, which stipulated that the gross weight of the vehicle and its load could not exceed 80 000 lb (36 288 kg). The empty vehicle weighed 35 000 lb (15 876 kg), and because the wet-drained GAC weighed roughly twice as much as dry carbon, two separate hauls were required to reactivate the 40 000 lb (18 160 kg) of dry carbon for each utility.

The truck was loaded and off-loaded by the hose and eductor system that had been used in the original MWW on-site reactivation operation. Filling the truck took 4 to 5 hours, whereas off-loading took about 1.5 to 2.5 hours. Differences between the filling times and the emptying times were due to a constant flow of carbon to the eductor during emptying and an intermittent flow during filling.

The sequence of operations was:

(1) Dispatch an empty truck to the participating utility.

(2) Return the truck to MWW with a load of wet-drained spent carbon (approximately 20 000 lb [9000 kg] dry).

(3) Start up the reactivator, reactivate the carbon, and shut down the reactivator.

(4) Return the first load of reactivated GAC to the utility.

(5) Pick up the second load of spent carbon (approximately 20 000 lb [9000 kg] dry) and return to MWW.

(6) Repeat procedure for step 3.

(7) Return the second load of reactivated GAC to the utility.

(8) Proceed to the next utility and repeat the sequence.

Once the truckload of GAC arrived at MWW, reactivation of the 20 000 lb (9000 kg) (dry) of carbon was accomplished in about 40 hours (at a 100-percent uptime operating factor). The reactivation process soon became routine. Carbon feed rates, temperatures, and pressures varied slightly because of the different types of GAC and adsorbent loadings, but process adjustments were easily made.

The Connecticut Water Company's Kelseytown treatment plant was the first to participate in the regional program. Regional reactivation was then provided to the Danvers and Lowell treatment plants. All three conventional water treatment plants used GAC primarily for taste and odor removal. The regional reactivation program was conducted in November and December 1981, and reported costs are based on actual expenses incurred during that time.

A summary of the unit costs for regional GAC reactivation for the three utilities is given in Table 5, which clearly demonstrates the cost-effectiveness of regional reactivation for these utilities. The actual cost of regional reactivation for the Connecticut Water Company was $0.6624/lb ($1.4603/kg) versus complete virgin replacement at $1.007/lb ($2.2045/kg) and estimated on-site reactivation costs of $1.387/lb ($3.057/kg). For Danvers, regional reactivation was $0.375/lb ($0.8267/kg) versus replacement at $0.634/lb ($1.3977/kg) and on-site reactivation costs of $1.389/lb ($3.062/kg). For Lowell, regional reactivation was $0.4495/lb ($0.9909/kg) versus replacement at $1.005/lb ($2.2156/kg) and on-site reactivation costs of $0.773/lb ($1.704/kg). The on-site reactivation alternatives were not cost effective because of the very high unit costs associated with small reactivation facilities and operations.

An itemized breakdown of the costs of regional reactivation for the three water utilities is shown in Table 6. The cost of regional reactivation for the Connecticut Water Company (CWC) was found to be considerably higher than the costs for the other two utilities. The main reasons for this were that (1) CWC experienced a higher carbon loss and therefore used more GAC for makeup, and (2) the transport distance between CWC and MWW was significantly longer than between MWW and the other utilities. The higher carbon losses incurred with the GAC from CWC were probably related to the type of carbon used. Connecticut Water Company used a lignite-based adsorption media, whereas the carbon used by the Danvers and Lowell plants was coal-based. Because the lignite-based carbon is softer than coal-based, abrasion losses are suspected to be greater with this material. The total volumetric carbon loss was 23.5 percent for CWC, 15.3 percent for Lowell, and 11.5 percent for Danvers.

Comparison of Tables 4 and 6 reveals that the costs of various items associated with regional reactivation were higher than the costs for on-site reactivation of MWW's own carbon. Several factors contributed to this:

- Costs were high because of the inefficiency of "first-time" operation; optimum furnace conditions could not be established with a small amount of carbon.
- The unit cost for makeup carbon was higher for regional operation because greater losses were experienced by the three participating utilities and the purchase cost of the makeup carbon was higher for the small quantities of carbon involved.
- Labor costs for GAC transport were higher because of off-site GAC handling and hauling.
- Unit costs for maintenance materials were higher because total cost was based on a small amount of GAC being reactivated over a short period of time.
- Labor costs for reactivation were higher because an increased workforce was assigned to the experimental program to ensure smooth operation (this is expected to be lower in normal regional reactivation operations).
- Fuel, electrical power, and water costs were higher because frequent reactivator startups and shutdowns resulted in greater consumption of these resources. This could be minimized in future operations by using two trucks instead of one. A two-truck transport operation would ensure a continuous flow of carbon to the reactivator, thereby reducing the need for shutdown.

Summary and conclusions

Regional reactivation provides an opportunity for minimizing the costs of reactivating granular activated carbon, particularly for small utilities that may be concerned about the high unit costs of reactivation. A research study was conducted in cooperation with the Manchester (N.H.) Water Works to examine the concept of regional GAC reactivation. The Connecticut Water Company and the Danvers, Mass., and Lowell, Mass., water utilities also participated in the study. Each of these utilities provided approximately 40 000 lb (18 160 kg) of carbon to be transported to MWW and reactivated.

Results of the study demonstrated that on-site reactivation at Manchester was considerably cheaper than replacing spent carbon with virgin carbon. Regional reactivation proved to be cheaper for the utilities than either replacement or estimated on-site reactivation, even when the costs of transportation and carbon loss were taken into consideration. The effect of economies of scale was demonstrated by this project, with the small utilities clearly benefiting from participation in a regional system. Therefore, regional reactivation, as anticipated, may provide a cost-effective alternative to either replacement or on-site reactivation for small utilities.

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